International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Efficiency of a Wastewater Treatment Plant in the City of Nairobi

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Abstract

Efficiency of a wastewater treatment plant in the city of Nairobi was evaluated by investigating water quality parameters. A total of 48 water samples were analyzed from the plant in three sites namely; Inlet (I),Clarifier (C) and Outlet (O) to determine physico-chemical ,inorganic ions, oil & grease, bacterial and heavy metals. The physico-chemical parameters analyzed included settleable solids (SS), chemical oxygen demand (COD), and biochemical oxygen demand after five days (BOD_5). The results for sampling sites I, C and O ranged from; settleable solids (6.5-15.7 ml/l, 0.2- 0.9 ml/l, 0.25- 1.9 ml/l respectively); COD (600- 4000 mg/l, 80- 120 mg/l, 70-115 mg/l respectively); BOD_5 (310-650 mg/l, 60-290 mg/l, 60-210 mg/l respectively); nitrates (0.158-1.437 mg/l, 0.167-1.178 mg/l, 0.132-1.00 mg/l respectively); phosphates (76-200 mg/l, 82.5-179 mg/l, 86-127 mg/l respectively); oil and grease (1.012- 1.901 mg/l, 1.1246-1.349 mg/l, 0.923- 1.032 mg/l respectively); Total coliforms (253,000- 590,000 counts/100 ml, 180,000 -561,000 counts/100 ml, 160,000- 783,000 counts/100 ml respectively. Percentage reduction efficiency for settleable solids was found to be in the range of 74.7- 96.7 % while COD and BOD_5 had percentage reduction efficiency ranging from 88.3- 98% and 43.6 - 84.5 % respectively. Nitrates and phosphates had percentage reduction efficiency of the range 17-36.5 and 13.2- 36.5 respectively. Oil and grease had percentage reduction efficiency in the range of 14.4 - 92.6 % while total coliforms had percentage reduction efficiency of 32.7 - 66.9 %.

Keywords: Wastewater; influent; effluent; efficiency; clarifier.

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1. Introduction

Kenya is classified a country with limited water supply with per capita accessible water presently at 650 m^3 per year and future outcrop shows a likely drop to 359 m^3 per year by 2020, due to population increase [1]. This number is far-off much less than the international acknowledged value of 1000 m^3 per year per capita level. Imperative action is thus required to boost the water capacity to advance the availability and ease of access to clean and safe drinking water [2]. Water pollution is a limiting factor for development in Nairobi City and other parts of the country [3]. It is therefore prudent to pay more attention to wastewater as a major water source if well treated to suit a given purpose. Nairobi City Water and Sewerage Company is the body charged with the responsibility of collection and treatment of wastewater in the city. However, the city's wastewater management systems have not been able to keep up with the increase in demand for cleaner water from the ever growing population which is estimated to be at 4 million currently [4]. The systems have proved insufficient to handle the amount of municipal and industrial effluent released into Nairobi River and other surface waters. Nairobi is no longer the "place of cool waters" but one in which the surface water is no longer potable or fit for many other useful purposes. A good number of industries located in Nairobi's industrial area discharge their wastes directly into the environment particularly into Ngong River thus making it the most polluted river in Kenya [5]. The amount of untreated effluent discharged into the river has made it a flowing effluent. Petro-chemicals and metal compounds from micro-enterprises and informal sector are some of the industrial wastes that are always released into the environment. Oil and grease from informal garages are usually washed into adjacent water systems. Due to poor sewage systems, some of these wastes usually find their way into the available sewer lines making the treatment processes ineffective [6]. Untreated or partially treated sewage and uncollected garbage have immensely contributed to a vicious cycle of water pollution, water-borne diseases, poverty, and environmental degradation [7]. Untreated or partially treated sewage poses environmental and health risks to people living in Nairobi and its environment, especially the poor who usually use contaminated waters and raw sewage for irrigation, subjecting both farm workers and consumers of the food crops to possible health problems [8].

2. Methodology

2.1. The study area

Kariobangi Sewerage Treatment Works (KSTW) is located in Kariobangi, Eastern part of Nairobi City County and it is a conventional mechanical plant with an in-built methanation unit. KSTW originally had a daily treatment capacity of 32,000 m^3 and currently discharges about 8,000 m^3 per day of partially treated effluent to the Nairobi River system, about 7 km downstream and north-east of the city centre. The plant receives wastewater from the city's sewerage network. Figure 1 shows the spatial location of Kariobangi wastewater treatment plant

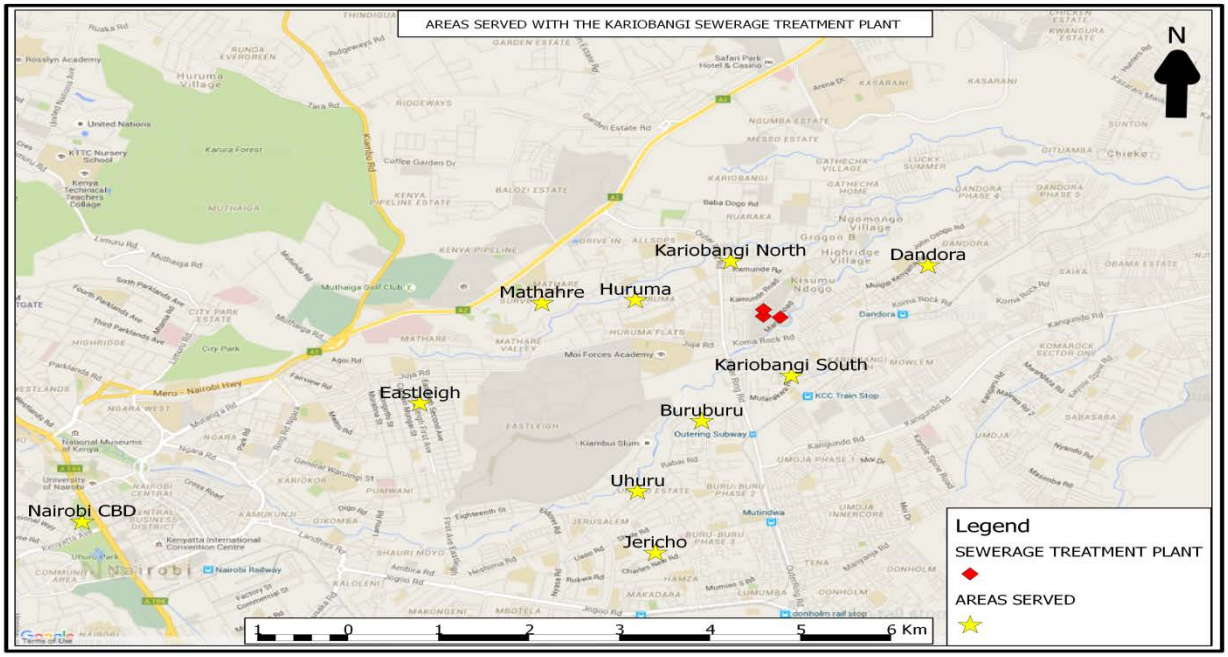

Figure 1: Spatial location of Kariobangi Wastewater Treatment Plant

2.2. Wastewater Sampling

Wastewater sampling was done for a period of four months starting from February 2015 to May 2015. Grab water samples were collected at the sites I, C and O within the plant using a sampler. Three-litre plastic bottles were used to carry the samples. Glass containers were used to carry samples for bacteriological determination. At each sampling point, the wastewater samples were taken in quadruplicate that gave rise to 12 samples per each sampling session and 48 for the entire study period.

2.3. Sample Analysis

2.3.1. Determination of physico-chemical properties

Settleable Solids

An Imhoff cone was filled to the 1litre mark with the sample. The sample was left to settle for 45 minutes. The sample around the side of the cone was gently agitated with a rod then allowed to settle for a further 15 minutes. The volume of settleable solids in the cone was recorded in milliliters per litre.

Chemical oxygen demand (COD)

2.5 ml of the sample was measured and put into digestion tubes. 1.5 ml of digestion solution (0.0139 M potassium dichromate) was then added followed by 3.5 ml of acid reagent (5.5 g Ag_2SO_4 added to 500 conc. H_2SO_4). The tube was cupped tightly and inverted severally for thorough mixing. The mixture was then digested using a thermo reactor preheated at 150°C for 2 hours. The digested mixture was allowed to cool and then transferred into 100 ml conical flask. Two drops of ferroin indicator were added, the mixture titrated using 0.125

M ferrous ammonium sulphate and the results tabulated.

Biological Oxygen Demand after five days (BOD_5)

45.7 ml of I sample, 97 ml of the C sample and 164 ml of the O sample were each put in a different BOD bottle. A breather was fixed and a pellet of sodium hydroxide added from the breather. The automatic reader stopper was then fixed and the bottles incubated in the Oxitop box for a period of five days. The readings for each day were taken and tabulated.

2.3.2. Chemical Parameters

Nitrate

Nitratest Tube was filled with a sample up to 20 ml mark. One level spoonful of nitratest powder and one nitratest tablets were then added. The cap was replaced and the tube shaken for one minute. The tube was allowed to stand for about one minute then gently inverted three times to aid mixing. The screw cap was then removed and the clear solution decanted into a test tube and filled to the 10 ml mark. One Nitricol tablet was added, crushed and mixed till it dissolved. The mixture was allowed to stand for 10 minutes till colour developed. The tubes were then inserted into a photometer (640 nm) from which the readings were then taken

Phosphate

The Tubetest heater was turned on, control set to 105°C and allowed to heat up to 105°C. The caps of the Tubetests Total Phosphorus/12 were removed and 2.0 ml of the three sets of the samples were added using a pipette. Two digest ox tablets were added to each tube, crushed and then mixed until it dissolved. The cap was tightly replaced and the tubes inverted gently until mixed. The contents of the tubes were then digested for one hour then removed, the tubes placed in the test tube rack and allowed to cool. The cap was carefully removed from the cooled tubes and 2.0 ml of PhosNeut Solution added using a pipette. One PhosNo. 1 tablet was then added, crushed then mixed to dissolve. One Phos No.2 tablet was then added, crushed then mixed to dissolve. The tubes were gently inverted several times until complete mixing was achieved. The tubes were then allowed to stand for 10 minutes so as to allow color development. The readings were taken at a wavelength of 640nm on a photometer

2.3.3. Determination of Oil and grease

100 ml of the sample was put into a 250 ml separating funnel. Three drops of sulphuric acid was added to bring the pH to 2 (to prevent oxidation). 50 ml of n-hexane at 50°C was then added and the mixture shaken so that any oil or grease present in the aqueous phase can migrate to the organic solvent phase. After thorough mixing the upper organic layer was drained off into a conical flask filled with anhydrous sodium sulphate. The contents of the conical flask were then filtered into a pre-weighed 250 ml round bottomed flask. The organic layer was then evaporated using hot water bath leaving the oil and grease. The flask was then weighed.

2.3.4. Determination of total coliforms

14g of nutrient agar was weighed, dissolved in 500 ml of distilled water. This was then heated using hot plate for complete dissolution. The solution was then put into autoclave for 15 minutes for sterilization. 0.1, 0.5 and 1.0 ml of the I, C and O samples diluted 1000 times respectively were put into Petri dishes. 15ml of the culture media were added. The samples were then cultured in an incubator for 24 hours and the results tabulated.

2.3.5. Determination of the heavy metals (Cadmium, Chromium and Zinc)

100 ml of a well-mixed acid preserved sample was transferred into a 250 ml conical flask. 5ml of conc. HNO_3 was added and agitated using magnetic stirrer. This was then brought to a slow boil and evaporated on a hot plate to 15 ml before precipitation occurred. This was heated while adding concentrated HNO_3 as was necessary until digestion was complete. This was showed by a light-colored, clear solution. The walls of the flask was washed down with distilled water then filtered. The filtrate was then transferred to a 100 ml volumetric flask and washing of the flask done with two 5 ml portions of water and the rinsings added to the volumetric flask. This was then cooled, diluted to the mark and thoroughly mixed. 20 ml of each sample was then aspirated into the AAS to determine the concentrations.

3. Results and Discussion

3.1. Physico-Chemical properties

Settleable Solids

There was gradual increase in the values of the settleable solids obtained for the influent from February to May 2015 as shown in Table 3.1. This could be attributed to the heavy downpour which washed into the sewer lines large amount of solid particles. The clarifier values were relatively lower compared to the effluent values. This could have been due to lower retention time of wastewater in the clarifier. The reduction efficiency ranged from 74.7-96.2 % which was commendable.

Table 3.1: Settleable Solids analysis results for the period ranging from February to May 2015

Month	I (ml/l)	E (ml/l)	% Reduction	C (ml/l)
February	6. 5±0.1	0.25 ±0.02	96.2	0.5 ±0.1
March	7.5 ±0.2	1.9 ±0.2	74.7	0.2 ±0.1
April	12.5±0.4	1.8 ±0.3	85.6	0.6 ±0.1
May	15.7±0.2	1.4 ±0.1	91.1	0.9 ±0.2

Chemical Oxygen Demand (COD)

March 2015 recorded COD value of 4000 mg/l for the influent while May recorded 600 mg/l. The values of the

clarifier were higher compared to the effluent values particularly in the months of March and May with COD values of 420 mg/l and 180 mg/l respectively.

Table 3.2: Chemical Oxygen Demand results for the period ranging from February to May

Month	I (mg/l)	E (mg/l)	% Reduction	C (mg/l)
February	1200±20	212±1	82.3	296 ±3
March	4000±10	280±2	93.0	420±5
April	1080±15	315±3	70.8	305±2
May	600±5	170±1	71.7	180±1

The percentage reduction efficiency for COD was quite high for all the months ranging from 70.8 – 93.0 %. However, none of these translated to effluent discharge standards as provided for by national environment management authority (NEMA) Kenya.

Biochemical Oxygen Demand for five days (BOD_5)

February recorded the highest value of 650 mg/l while May recorded the lowest value of 310 mg/l for the influent. The clarifier values were lower than the influent values. The percentage reduction efficiency was in the range of 56.9- 64.5 % as shown in Table 3.3.

Table 3.3: Biochemical Oxygen Demand analysis results

Month	I (mg/l)	E (mg/l)	%Reduction	C (mg/l)
February	650±5	280±2	56.9	360±1
March	550±10	210±3	61.8	290±2
April	380±2	150±5	60.5	190±5
May	310±1	110 ±2	64.5	150±2

3.1.1. Chemical Parameters

Nitrates

The nitrate values obtained for the influent over the period was much lower as shown in Table 3.4 than the allowable limits of 20 mg/l. This could be due to low discharge of nitrogen containing substances such as fertilizers into the sewer lines as a result of low level of agricultural activities along the sewer lines. There was

gradual increase in the influent values with May recording the highest value of 1.437 mg/ l. Reduction efficiency ranged from 15.0 -36.5 %

Table 3.4: Nitrates analysis results

Month	I (mg/l)	E (mg/l)	% Reduction	C (mg/l)
February	0.902±0.001	0.770±0.08	17.1	0.924±0.002
March	0.158±0.002	0.132±0.001	16.5	0.167±0.003
April	1.178±0.001	1.001± 0.002	15.0	1.178±0.002
May	1.437±0.003	0.912±0.003	36.5	1.100±0.01

Phosphate

The phosphate values obtained for the influent over the period were much higher as indicated in Table 3.5 than the allowable limits of 30 mg/l PO_4. This could be due to high discharge of phosphate containing substances such as detergents into the sewer lines. There was gradual increase in the influent values with May recording 200 mg/ l PO_4. Reduction efficiency ranged from 13.2 – 36.5 %.

Table 3.5: Phosphate analysis results

Month	I (mg/l)	E (mg/l)	% Reduction	C (mg/l)
February	86±2	76±1	13.2	86±2
March	142.5±1.0	92.5±0.1	35.1	82.5±0.5
April	159±2	123±1	22.6	143±1
May	200±3	127±3	36.5	179±1

3.1.2. Oil and grease

The influent values of oil and grease obtained over the period were lower than the recommended value of 10 mg/l.

Generally the effluent values were lower compared to the influent as shown in Table 3.6. Clarifier values ranged from 1.125 to 1.349 mg/l compared to influent values which ranged from1.012 to 1.901 mg/l.

Table 3.6: Oil and grease analysis results

Month	I (mg/l)	E (mg/l)	% Reduction	C (mg/l)
February	1.079±0.011	0.923± 0.001	14.4	1.179±0.002
March	1.012±0.001	0.075±0.001	92.6	1.178±0.012
April	1.587±.0.012	1.000±0.100	37.0	1.125±0.001
May	1.901±0.003	1.032±0.002	45.7	1.349±0.002

The percentage reduction efficiency was in the range of 14.4% - 92.6 % as shown in Table3.6. The months of March and May recorded the highest reduction efficiency for oil and grease while February recorded the least percentage reduction efficiency for oil and grease.

3.1.3. Heavy Metals

Cadmium

There was gradual decrease in the influent values ranging from 0.5055 to 0.7230 mg/l. The cadmium levels for the clarifier and the effluent were higher than the influent values except for April effluent value which was lower. The effluent levels were way above the recommended discharge level into the environment which is 0.01 mg/l. February recorded 1.4465 mg/l while May had 0.8500 mg/l as shown in Table 3.7a. This great difference between the influent and the effluent values could be attributed to possible accumulation of cadmium in the clarifier and wastewater pathways within the treatment plant. This is because Cadmium being a heavy metal is attached to the sludge material and other solids by adsorption.

Table 3.7a: Cadmium analysis results

Month	I (mg/l)	E (mg/l)	% Reduction	C (mg/l)
February	0.732±0.001	1.447±0.001	-	1.447±0.011
March	0.674±0.001	1.301±0.002	-	1.057±0.001
April	0.602±0.002	0.494±0.001	18.0	0.772±0.012
May	0.5055±0.0010	0.8500±0.01	-	0.9605±0.0001

Total Chromium

February recorded the highest influent value of 58.565 mg/l.; April recorded the least amount of 4.625 mg/l as shown in Table 3.7b. There was general decrease in the concentrations of chromium for the influent. Despite the elevated influent levels, the effluent levels were below the detection limit of 0.32mg/l except for the month of March which registered a concentration of 10.16 mg/l. The chromium concentrations for the clarifier were equally higher with April recording the highest value of 47.16 mg/l. The high clarifier concentrations could be due to accumulation of chromium here. Chromium being a heavy metal possibly got attached on the sludge surfaces.

Table 3.7b: Chromium analysis results

Month	**I (mg/l))**	**E (mg/l)**	**% Reduction**	**C (mg/l)**
February	58.565±0.211	< 0.32	-	35.125 ±0.001
March	51.605±0.121	10.16 ±0.11	80.3	41.080 ±0.201
April	4.625±0.001	< 0.32	-	47.160 ±0.130
May	43.755±0.044	< 0.32	-	3.715 ±0.113

Zinc

March recorded the highest value of 4.2335 mg/l. The effluent values were generally higher than the recommended maximum allowable limit of 0.5 mg/l except for the month of May which recorded a concentration of 0.1025 mg/l as shown in table 3.7c. This could be attributed to zinc usage in the cottage industries within the vicinity of the treatment plant.

Table 3.7c: Zinc analysis results

Month	**I (mg/l)**	**E (mg/l)**	**% Reduction**	**C (mg/l)**
February	2.883±0.001	1.422±0.003	50.7	0.606±0.231
March	4.234±0.001	1.936±0.012	54.3	2,184±0.001
April	1.382±0.101	1.016±0.001	26.5	1.086±0.301
May	0.879±0.220	0.103±0.001	88.3	1.284±0.001

3.1.4. Total coliform

General decrease in the values of total coliform was observed from March to May. March recorded 783000 counts/100ml while May recorded 253,000 counts/100ml total coliform for influent. The values of total coliform for the clarifier were relatively lower than the values for the influent. The effluent values were also lower

compared with the respective influent values.

Table 3.8: Total Coliform analysis results

Month	I (mg/l)	E (mg/l)	% Reduction	C (mg/l)
February	483000±1000	160000±50	66.9	180000±50
March	783000±1000	590000±200	32.7	561000±400
April	352000±100	243000±120	31.0	267000±300
May	253000±150	189000±90	25.3	223000±100

4. Conclusion

BOD, COD, Oil & grease and total coliforms had effluent values higher than the National Environment Management Athourity (NEMA-Kenya) guidelines of 30 mg/l, 50mg/l, Nil and 30 counts/100ml respectively.

Settleable solids, BOD except March, COD, oil and grease; March, and total coliforms; February had greater percentage reduction efficiency ranging from 74.7 - 96.2 %, 56.9-64.5 %, 70.8- 93.0 %, 92.6 %, and 66.9 % respectively;. However, despite the high percentage reduction efficiency, the effluent values for BOD, COD, Oil and grease and total coliforms were still higher than the maximum allowable limits.

The concentrations for COD, BOD were affected by the change in season. There were higher concentrations in dry season that is February-March compared to the wet season lasting between April and May. This was due to dilution of the wastewater by the storm waters. On the other hand the levels of settleable solids were high during the wet season compared to the dry season. This was due to increased surface run-offs.

Acknowledgment

I would wish to acknowledge the support received from the staff at Nairobi City Water and Sewerage Company for allowing me to carry out this work at one of their facility. My appreciations also go to Kenya Water Institute (KEWI) where the laboratory work was done. More thanks to University of Nairobi and Technical University of Kenya. Last but not least I wish to thank Nuffic for their financial support to carry out this piece of work.

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